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APPROACH AND METHODOLOGY
December 1978

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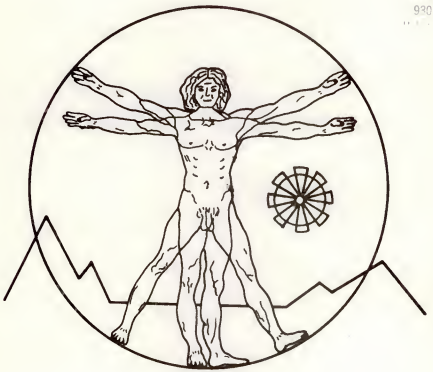

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Front cover illustration is based on a drawing by Leonardo da Vinci that has come to symbolize human health.

APPROACH AND METHODOLOGY

DECEMBER 1978

MONTANA AIR POLLUTION STUDY

Air Quality Bureau
Environmental Sciences Division
Department of Health & Environmental Sciences
Cogswell Building
Helena, Montana

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SECTION I

INTRODUCTION

This document is one of a series of reports on the Montana Air Pollution Study (MAPS), a project being conducted by the Department of Health and Environmental Sciences through the Environmental Sciences Division's Air Quality Bureau. Developed in response to House Bill 250, enacted by the Forty-Fifth Montana Legislature, the MAPS project is an ambient air monitoring and health effects study intended to improve our knowledge of air pollution in the state and to investigate the relationship between air pollution and the health of Montana's residents.

This specific report is intended to document for the public record a discussion of the background, the planning and development, and the implementation of the MAPS project. It does not contain results or conclusions; these will be presented in a series of specific-subject reports through the remainder of the project, and in a final report after the termination of the study on June 30, 1979.

The goal of this report is to make available, in advance of any major results or conclusions, a discussion of the way in which the project was formulated, the questions to be answered, the objectives to be met, and so on.

The Department and the Air Quality Bureau consider it particularly important that interested parties in the state have an adequate opportunity to understand thoroughly the issues underlying the MAPS study and its results, so as to make possible a thorough, knowledgeable discussion of the results and conclusions as they become available.

The matter of air pollution and public health has been an issue involving major technical and public policy debate for many decades, and it is not likely that even a major study such as MAPS will completely resolve the issue. Rather, it is likely that the new information, tailored more specifically to Montana, will tend to move the discussion of the issue to a more detailed level, so that an understanding of the technical background of the information will be of some importance. This document is meant to contribute to that understanding. The staff of the MAPS project and the Air Quality Bureau will of course be happy to provide any other information required.

SECTION II

PROJECT PLANNING & DEVELOPMENT

This section describes the background and history of the MAPS project planning effort and the reasons for the various decisions made.

Initial Project Development

The concept of developing a major state study of air pollution health effects originally arose out of a discussion concerning unusually high death rates from chronic pulmonary disease and lung cancer in several Montana counties, which were identified in a review of death certificates by the Department's Bureau of Records and Statistics. Since these categories of lung diseases are felt by many to be caused or worsened by high air pollution levels, a more extensive study of the subject seemed warranted. Prior to this study, all air pollution and health research had been conducted by major medical research universities and the federal government, and the results were generally seen as not necessarily applicable to the unusual terrain and meteorology of Montana, or to many of the less-populated parts of the nation, for that matter.

Consequently, the Air Quality Bureau suggested to the Legislature that a study be undertaken, and the Forty-Fifth Legislature did enact HB 250 to mandate and fund such a project, the first time that a state has made a significant research effort to evaluate its own potential air pollution and health situation.

In response to the passage of HB 250, the Air Quality Bureau developed a proposed project plan for the Montana Air Pollution Study, to be conducted during the 1977-79 biennium. Drafts of the proposed plan were made avail-

able in May 1977 and public hearings were held. The approved plan offered three major goals for the effort:

> Develop a comprehensive body of information on air pollution levels, meteorology, pollutant emissions, and topography and how these factors relate to the effects or impacts on the public;
>
> Determine where possible the health impacts of selected air pollutants on the populace of specific areas of the state (areas designated in the law are Butte-Anaconda, Missoula, Billings, Columbia Falls, East Helena, and the Colstrip-Hardin Southeast coal development region);
>
> Develop an early warning system to prevent the occurrence of episodes of high air pollutant levels that could cause possible health damage.

The plan further defined nine specific objectives designed to implement these goals:

1. Comprehensive information system
2. Air resources modeling system
3. Air resources data bank
4. Ambient air monitoring
5. Meteorological studies
6. Emission inventory
7. Health monitoring
8. Health impact correlation
9. Early warning system

The May 1977 project plan also defined an organizational structure for coordinating the MAPS project within the staff of the Department, mainly in the Air Quality Bureau, and established five advisory committees to assist the Bureau in tapping all the relevant expertise available in the state.

During the development of the project plan, the Bureau staff sought expertise and guidance not only from within the state, but also from representatives of the federal Environmental Protection Agency and various individuals and firms involved in environmental consulting and contracting. The concern for developing an adequate and readily-accessible data base, as expressed in the first project goal, was given additional emphasis in

response to the general opinion of outside experts. These advisors felt that some of the anticipated health effects correlations could not be documented properly in a short-term, ad hoc study, and emphasized their opinion that a longer-term, more organized and extensive data gathering effort should be undertaken.

The previous point also serves to highlight a major concern of the Department about the overall management and staffing of the MAPS project. The existing Air Quality Bureau staff could not undertake the complete project in addition to their normal functions, and it appeared necessary to engage the services of one of the commercial or institutional consulting organizations that do contract research in the environmental sciences field. This approach has two major disadvantages, however. First, primary reliance on a contractor would minimize the integration of the project efforts with other Bureau activities, and hence would leave much less behind after the project in the way of improved data gathering, expanded expertise, and so on. Second, conducting the project through a contractor would be much more expensive, requiring a corresponding reduction in project scope.

During the period of contact with various consultants, one firm (GCA Corporation of Massachusetts) made a specific proposal to undertake as a short task the next logical steps in project development. This proposal was accepted as a desirable means of continuing project development without necessarily committing the entire project to a consulting firm, so GCA undertook to define detailed tasks and make cost estimates based on the proposed project plan.

Task Definition and Cost Estimation

The purpose of the contractual effort undertaken by GCA was to extend project planning from the initial conceptual plan into the initial stages

of an operational study effort. This involved organizing the proposed work effort into specific tasks, with alternative approaches where possible. GCA was also required to develop cost estimates for the various tasks, to assist in the prioritization of the tasks into a study scope commensurate with the budgetary appropriation, and to develop draft scopes of work and other procurement documents relating to some of the high priority tasks requiring early initiation. The time restrictions involved in trying to conduct a study of the magnitude of MAPS within a single biennium are necessarily tight; hence the GCA personnel worked very closely with the Bureau staff and the Advisory committees in order to minimize any time lost in iteratively arriving at conclusions. Consequently, the definition of tasks and their prioritization within the budget was in many ways a common effort among the MAPS staff, the Advisory Committees, and the GCA project manager.

Through interviews with staff members, other potential resource people and firms, as well as through the meetings of the various advisory committees, a list of possible approaches and suggested components to the various portions of the study was assembled. Where possible, a variety of options was included, although suggested options that were clearly not feasible were discarded. In this fashion, a list of tasks was defined and costed. This task list was categorized into the six technical areas identified in the proposed project plan, and task descriptions and cost estimates were prepared.

Unfortunately, the total of the cost estimates was such that if every suggested task were undertaken to its desired extent, the overall project cost would have been approximately $3 million, a sum that exceeded the appropriation by nearly a factor of three. Consequently, a major effort to define

priorities among the tasks was required. Priorities were required in each technical area, reflecting the relative importance of the various tasks in meeting the objectives in that area, and priorities were also required among all the higher priority tasks together, reflecting the relative importance of the various technical areas in meeting the overall goals and objectives of the entire MAPS project.

Because the costs required such a severe reduction in the task list, the Air Quality Bureau used a careful, thorough, somewhat formalized system in the prioritization process. This system, the entire prioritization process, and the lists of tasks are documented in the GCA final report entitled "Initial Task Planning." The result of the task planning efforts was a list of the defined tasks in three priority groupings, as listed in Table 1 (the detailed tasks have been combined into generic groups for brevity and clarity). The first group of tasks was considered essential and had to be implemented quickly. The second group was similarly important, but could be deferred somewhat in time to permit a possible reassessment after the actual costs of some of the first group had been defined by actual procurement. The first two groups of tasks together were those that could reasonably be attempted within the budget; the third group of tasks included those that had to, as a matter of budgetary necessity, be reserved for implementation only if funds permitted.

TABLE 1. PRIORITY GROUPING OF TASKS

PRIORITY I.	Essential to the basic core of the MAPS, and require immediate implementation.
	- Pulmonary function studies and associated support efforts
	- Carcinogen/mutagen screening study
	- Morbidity data studies
	- Mortality studies in secondary MAPS cities
	- Areawide total and respirable particulate monitoring, with associated analyses
	- Continuous gaseous pollutant monitoring
	- Meteorological support monitoring in Missoula and Billings
	- Basic design of data management system and standards and effects subsystem
PRIORITY II.	These tasks are required for the completion of the overall MAPS program objectives, although less fundamental or of less urgency than Priority I.
	- Initial development in support of episode prevention system
	- Emission inventory update and improvement
	- Meteorological support monitoring in Butte and Anaconda
	- Basic design and development of emission inventory and meteorological modeling systems
	- Historical emission inventory - initial feasibility study
	- Additional monitoring equipment for SO_2 and special studies
PRIORITY III.	These tasks are considered desirable, and supportive of MAPS program objectives, but must be held in abeyance pending the outcome of procurements.
	- Additional data studies of mortality in Billings and Missoula, and of physician visits in Billings
	- Alternative carcinogen/mutagen screening programs
	- Additional monitoring equipment for special indoor/outdoor studies
	- Special sulfate characterization study
	- Additional meteorological support monitoring
	- Further emission inventory development
	- Special emission factor development work
	- Further historical emission inventory
	- Extended data systems and modeling capability

Project Management Staffing

An important consequence of the necessary fiscal restraint was its influence on the decision concerning the contractual manner of conducting the project. In order to reduce costs as much as possible, it was decided to undertake the supervision and management of the project within the permanent Air Quality Bureau staff as much as possible, and not to hire a contracting firm for this role. This approach involves hiring project personnel directly as state contract employees, and also providing for the overall management and administrative responsibilities through individual personnel contracts. The project manager from GCA's project team was engaged as Technical Manager to assume overall technical and financial responsibility for the project, and an administrative coordinator hired for the transition period was engaged for the entire project duration. Under this "in-house" approach, the technical project officers on the Air Quality Bureau staff carry some significant additional responsibility for planning and supervision, but the necessity for further reducing the project's scope is avoided. To date the decision for in-house management appears to have been the proper one.

Overview of MAPS Technical Activities

The remaining sections of this report are intended to provide in some detail an outline of the technical content of the various activities within the MAPS project, i.e., the air quality and meteorology monitoring, the measurement of health effects, emission inventory efforts, and the data systems support. This last portion of the present section is intended to provide an overview of how the various activities interact with each other, and how they are directed at the goals and objectives of the entire MAPS project.

Figure 1 illustrates in a flow-chart fashion how the various parts of MAPS interact to achieve the goals, not only the health effects objectives, but also those objectives that are more analogous to existing Air Quality Bureau functions.

Under MAPS, there are four areas which are basic data-gathering activities -- the air quality, meteorology, and emission inventory, all of which amplify existing Bureau functions, plus health parameters monitoring, which is an unprecedented activity in the Bureau. The health parameters monitoring includes pulmonary function testing of school children and respiratory patients, as well as "Ames test" mutagen screening in the same two groups. Both health activities will be discussed in detail later in this report.

A comprehensive information system ties all of the above activities together and facilitates access to the data being generated by MAPS and the Bureau. The air quality and meteorology data are used for analysis with the health data to help develop the modeling and early warning systems. Through regular analysis, the data will also assist in the identification of sources and causes of air pollution. The meteorological data are the major resource needed to develop the modeling system, along with the air quality and emissions data. The modeling system not only contributes to the early warning system, but also facilitates the making of development and planning decisions.

The air quality data and the data on health parameters are the primary components required to develop health effects relationships, although the meteorological and emission data can help interpret the relationships in unusual cases. The results of the health effects correlation combine with those of other smaller data-base studies to provide an improved overall assessment of health effects-public policy issues.

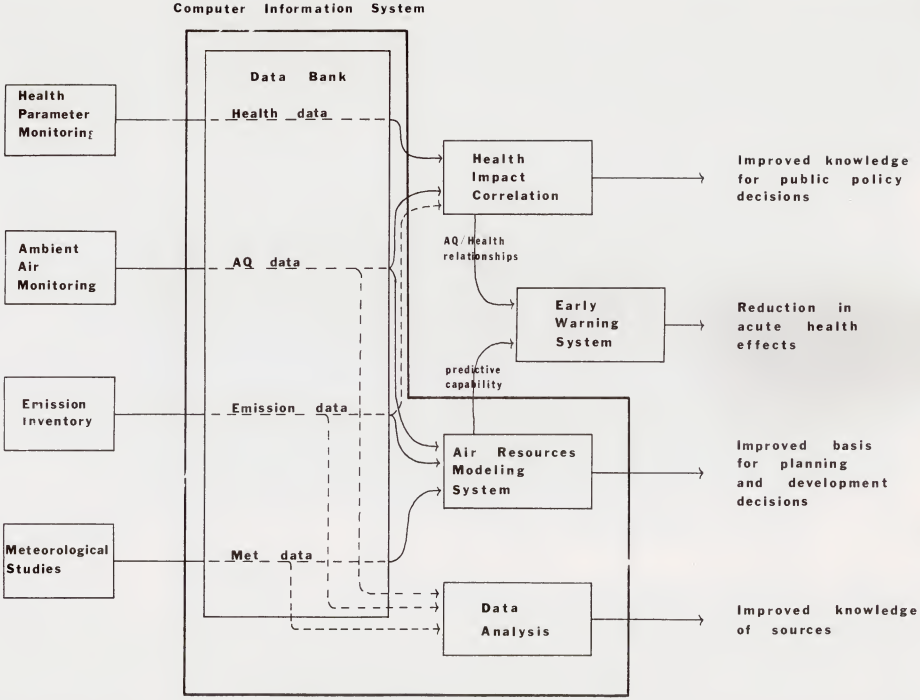


Figure 1. Inter-relationship Among
MAPS' Nine Operating Objectives

SECTION III

AMBIENT AIR MONITORING

All three of the objectives of the MAPS project involve the adequate monitoring of ambient, or outdoor, concentrations of air pollutants. The ambient air monitoring effort undertaken by MAPS includes measurement of the major gaseous air pollutants and of suspended particulates, study of the size and elemental composition of the particulate matter, and measurement of visibility reduction and some forms of ionic species. The data collected will be analyzed in conjunction with the meteorological, health effects and emissions data also being generated under MAPS. Because it is desired to provide a well-organized comprehensive data base, the additional MAPS monitoring effort has been thoroughly integrated with the Air Quality Bureau's normal monitoring activities, as well as those being conducted under other special projects.

The most current, EPA-approved, monitoring and calibration equipment and procedures are being utilized in the program. This will not only permit an adequate assessment of possible health effects, but will also assure that the data are acceptable for other air quality management purposes, such as EPA-mandated regulatory and enforcement efforts. In particular, a major attempt has been made to provide thorough and up to date monitoring of suspended particulate matter, one of the more serious pollutant problems in most Montana cities. Numerous chemicals and particles have been recently implicated as being carcinogenic or which otherwise adversely affect health. Thus, looking at only the major pollutants, such as sulfur dioxide, oxidants, oxides of nitrogen, carbon monoxide, total suspended particulates and hydrocarbons, for which standards or guidelines exist, is really insufficient to adequately document relationships between air pollutants and health. Consequently, detailed

study of elemental composition and the concentrations of some common ionic species is also included in the ambient air studies. More detailed description of the parameters monitored is presented later in this section.

Station Locations

The health effects portion of the project purpose requires the measurement of air pollutant levels in areas of population so as to quantify the exposure of the population, as opposed, for example, to measurement in the vicinity of an industrial pollution source to quantify its contribution to the overall problem. The selection of a number of sites in a populated area would be the most desirable way to quantify population exposure. However, because monitoring costs are high, it has been necessary to limit the major monitoring effort to a single site in each city. Consequently, choosing the location of that single station was a particularly important task in each study city.

The Air Quality Bureau's air monitoring personnel met with MAPS Advisory Committee members in each of the study cities to obtain their views on location of air monitoring sites. Because the health effects studies involved school children, elementary schools were located on maps and considered in the selection process. Bureau personnel selected possible areas and rated them according to nine categories: industry, school density, transportation density, general population, elevation (most critical in Butte), light industry and/or business, distance from roads with high traffic flow, and open ventilation around the site (absence of trees). Once agreement was reached on a recommended location, it was necessary to arrange permission to use the desired parcel of ground; this is a task where problems frequently arise. In Anaconda, Butte, and Missoula, this task went smoothly; however, in Billings we were unable to obtain the most suitable monitoring site. The site finally

obtained will characterize a more limited area of Billings than desired.

Maps of Anaconda, Billings, Butte and Missoula with the monitoring sites marked are shown in Figures 2 through 5 respectively. In addition to the major air quality sites, the map symbols depict additional air monitoring sites used for particulate monitoring equipment and meteorological monitoring activities. The location of the schools in the health studies is also indicated.

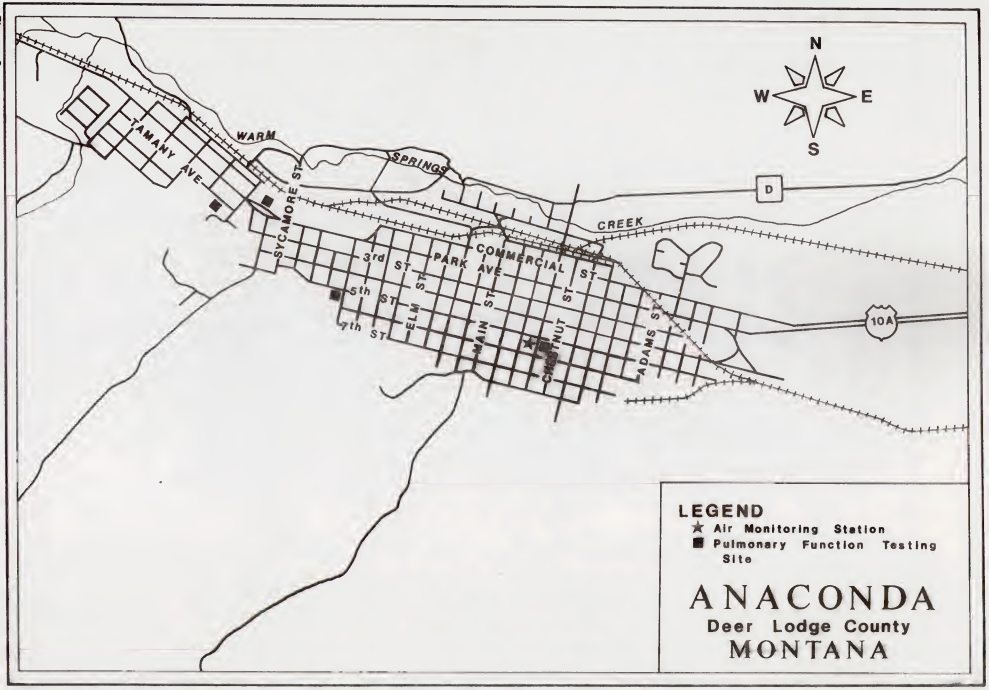
Table 2 shows a summary of characteristics of the major sites. In comparing data from city to city, it is of course desirable that the stations be as comparable as possible. However, while there is general similarity among the sites, there are also unavoidable differences from city to city. Generally, stations were placed about the same distance from busy major streets and within a mix of residential and light business.

TABLE 2

Qualitative Comparison of Characteristics of Major Sites

	Missoula	Butte	Anaconda	Billings
Elevation	3180	5550	5260	3150
Transportation density	3	2	1	2
General population density	4	2	2	3
Light business density	3	3	1	2
Industry density	1	3	3	1
Distance from hi-traffic roads	4	2	1	2
Ventilation of site	1	1	2	4
TOTALS	16	13	10	14

Rating: 1 = minor/low density (good), 4 = major/high density (bad).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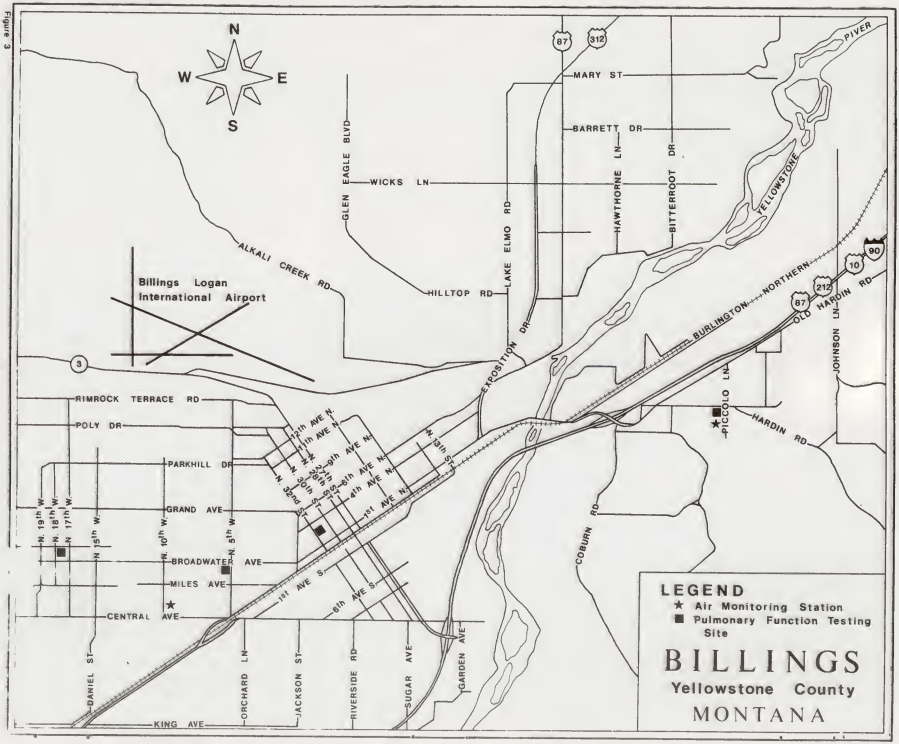
Air Monitoring Station
Pulmonary Function Testing Site
ANACONDA
Deer Lodge County
MONTANA

Figure 2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BITTERROOT DR
YELLOWSTONE
PIVER
Billings Logan International Airport
EXPOSITION DR
BURLINGTON NORTHERN
OLD HARDIN RD
JOHNSON LN
PICCOLO LN
HARDIN RD
RIMROCK TERRACE RD
POLY DR
PARKHILL DR
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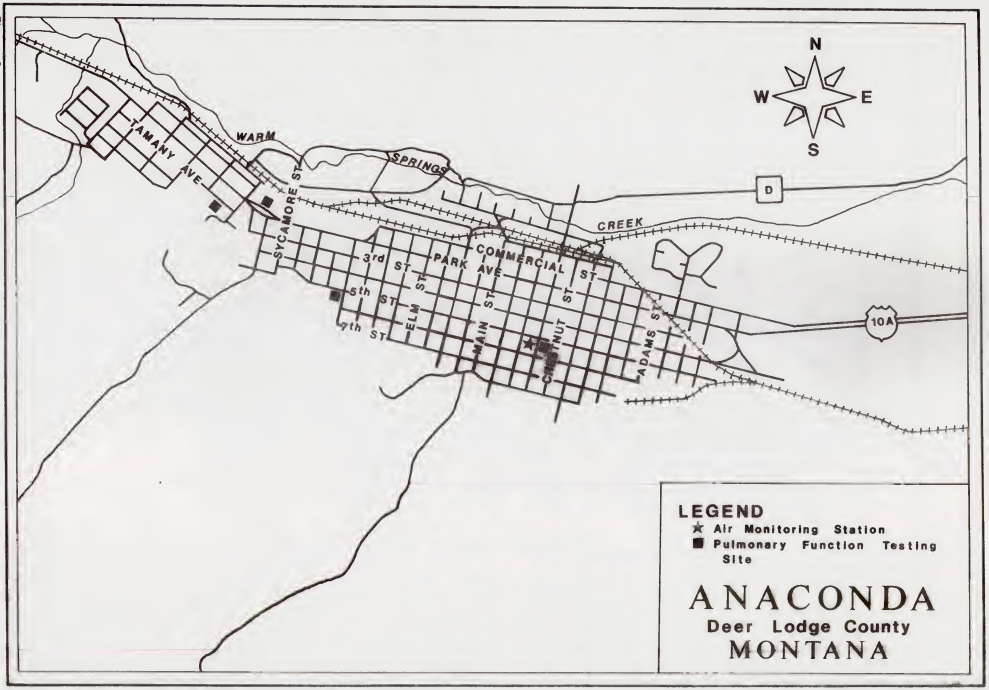
Pulmonary Function Testing Site
BILLINGS
Yellowstone County
MONTANA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ANACONDA
Deer Lodge County
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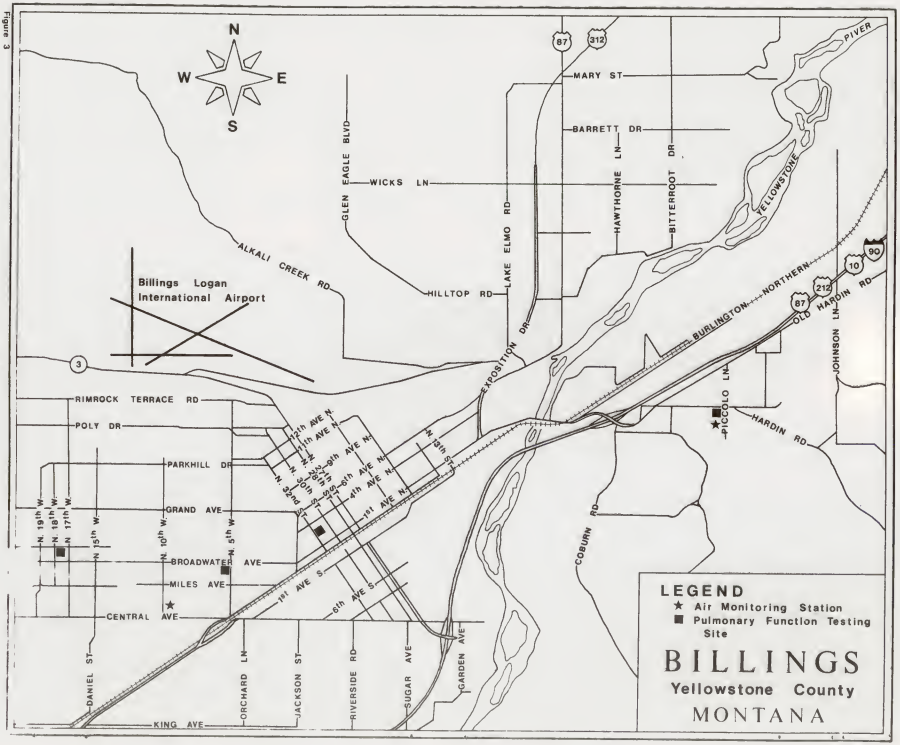
Figure 2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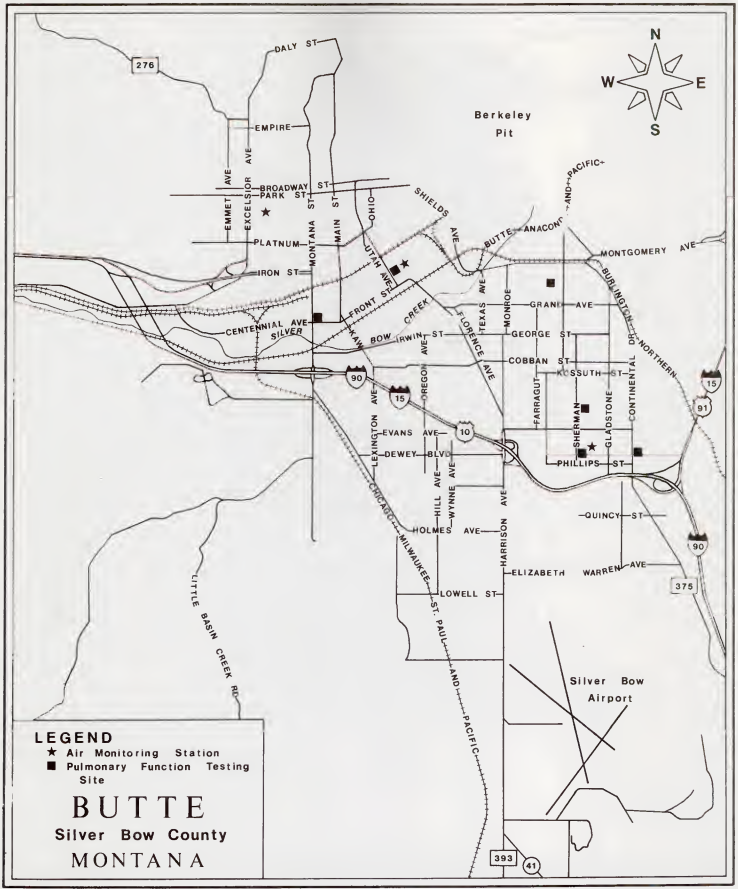
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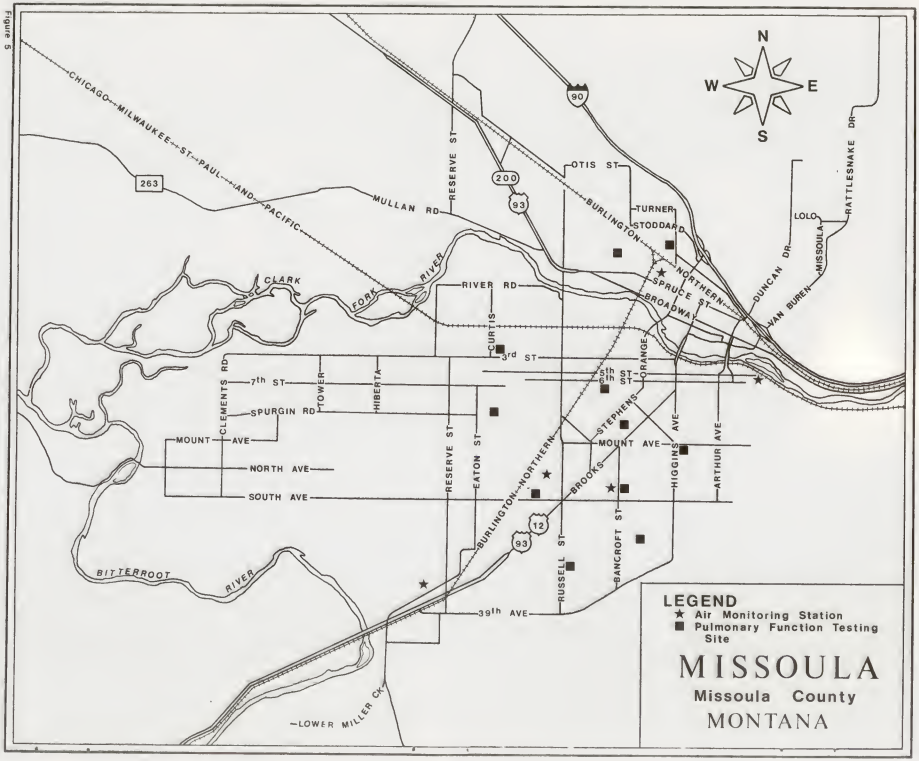
LEGEND
★ Air Monitoring Station
■ Pulmonary Function Testing Site
BUTTE
Silver Bow County
MONTANA

Figure 4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RUSSELL ST
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BITTERROOT RIVER
39th AVE
LOWER MILLER CK
LEGEND
★ Air Monitoring Station
■ Pulmonary Function Testing Site
MISSOULA
Missoula County
MONTANA

Gaseous Pollutant Monitoring

Because it involves sophisticated instruments with elaborate shelters, continuous monitoring of gaseous pollutants is a major undertaking; however, it is necessary to provide the quality and detail of data normally required for air quality purposes. The MAPS program has built upon and expanded the existing Air Quality Bureau monitoring network until each study city has a complement of up-to-date instrumentation for the major health oriented gaseous pollutants and, in some cases, for others as well. Table 3 summarizes the parameters available for use in MAPS, and the sites where they are located.

The monitoring network is operated in accordance with very-recently-promulgated EPA quality assurance guidelines. All the continuous monitors are calibrated routinely with special dynamic calibrators, which introduce precisely-known concentrations of gases into the instruments. Daily to weekly calibrations are made by the station operators, and independent monthly calibrations are made by the Bureau's Quality Assurance Coordinator. In addition, EPA audits the stations on a quarterly basis. The goal is for at least 90 percent collection of valid data.

Following the new EPA quality assurance guidelines required an investment in calibration equipment that was beyond that initially contemplated. However, the project was saved a considerable amount of funds through the procurement on long-term loan of four monitoring shelters that had been previously employed by EPA in St. Louis; one of these was fully equipped with a complement of instruments as well.

TABLE 3

SUMMARY OF AIR QUALITY MONITORING NETWORK

Gaseous Pollutant	Major Study Areas			
	Anaconda	Billings	Butte	Missoula
Sulfur Dioxide	Lincoln School Anaconda Co. (6 sites)	Central Park Lockwood Sch.	Hebgen Park	Lions Park Hoerner-Waldorf (3 sites)
Total Sulfur and H_2S				Lions Park Hoerner-Waldorf (3 sites)
Nitrogen Dioxide	Lincoln School	Central Park Lockwood Sch.	Hebgen Park	Lions Park
Ozone	Lincoln School	Central Park	Hebgen Park	Lions Park
Total hydro-carbons	Lincoln School	Central Park	Hebgen Park	Lions Park
Methane			Hebgen Park	
Carbon monoxide		Fairgrounds	Hebgen Park "Alpine West"	"Malfunction Junction"
Particulate Matter				
TSP (Hi-vol)	Lincoln School "Highway Junction" Anaconda Co. (3 sites)	Central Park Lockwood Sch. Yellowstone County (4 sites)	Hebgen Park AQB (3 sites) Anaconda Co. (5 sites)	Lions Park McLeod Park Missoula County (6 sites)
Particle-sizing virtual impactor	Lincoln School	Central Park Lockwood Sch.	Hebgen Park Floral Park	Lions Park McLeod Park Courthouse

Smaller Study Areas

East Helena: TSP, SO_2, virtual impactor
Colstrip-Hardin: TSP (2 sites), SO_2, NO_2, Ozone
Columbia Falls: TSP, virtual impactor, fluoride

Particulate Sampling

In several Montana cities, as is typical in relatively dry climates, a major pollutant is particulate matter, i.e., solid dust particles in the air. The traditional measure of this type of pollution is the total weight or mass, as measured by a hi-vol sampler, and all existing standards and regulatory procedures in the country are based on this type of data. However, the harmful effects of the particulate matter depend very much on the size of the particles. Consequently, it is desirable for many purposes, and almost mandatory for health effects research purposes, to measure the smaller, respirable particles separately.

This is not an easy task, and the development of instruments to do this is very much in a state of flux at the current time. In order to insure having an up-to-date network, the MAPS staff elected to purchase a type of equipment known as a virtual impactor or dichotomous sampler. These are very clearly the "wave of the future", as opposed to other instruments that are now becoming obsolete. A negative consequence of this decision was a long delay in delivery while the manufacturer stopped to revise the instruments to changing EPA guidance. With the receipt of the dichotomous samplers, however, the Montana state monitoring network became one of the very few efforts in the country to truly monitor particulate pollution properly. Coupled with the thorough chemical analysis of the samples, this will permit a much more scientific evaluation of particulate pollution problems in the state.

SECTION IV

METEOROLOGICAL MONITORING AND MODELING

The meteorological monitoring activities undertaken by MAPS are designed to meet several dissimilar needs. Some meteorological parameters, such as temperature, sunlight, precipitation, and possibly barometric pressure, directly affect the way people feel. This in turn not only influences their day-to-day health, but also may affect the results of the pulmonary function tests and other direct health measurements. Thus direct measurement of such parameters is necessary for proper interpretation of the basic data on health effects.

In a more traditional air pollution sense, meteorological parameters are also monitored for use in the analysis of air quality data and in the development of predictive models relating pollutant emissions and population exposure. Meteorological conditions are a major factor influencing the frequency and severity of people's air pollution exposures. The ability of the lower atmosphere to dilute, mix, and disperse pollutants released into it changes immensely from day to day and week to week, as well as from season to season and from one area to another. These meteorological variations account for most of the difference between experiencing quite high levels of pollution and relatively pollution-free conditions. Thus it is essential that such meteorological variations be measured and documented for analysis with the accompanying changes in pollution concentrations. Only through the analysis of air quality and meteorology together is it possible to describe, anticipate or predict accurately those atmospheric changes that may either increase or decrease pollution concentrations.

Monitoring meteorological conditions in Montana cities, however, is a particularly difficult and complex task. The air movements in the lower

atmosphere that occur over the mountainous terrain of the western part of the country are far more complex than those over flat terrain. The configuration of mountain valley terrain causes patterns of air movement that frequently change greatly over short distances. Several Montana cities are located in valleys almost entirely surrounded by mountains. In these areas air movement is quite restricted under certain meteorological conditions and the escape of pollutants from the valley "bowl" is very limited.

In addition to the problems of complex terrain, the existing meteorological data network is very sparse compared to that in urban areas in more populated parts of the country. The federal National Weather Service, which does most of the meteorological monitoring in the country, does not provide much coverage in Montana. Surface measurements of wind conditions, for instance, are made only at airports, for purposes of flight safety. However, because of the topography, most of Montana's airports are located such that the data gathered there is not at all representative of the areas where the majority of the population lives. Other National Weather Service data are even more remote and less useful; their upper air network (for measuring conditions up to 3000-5000 feet) is meant to help in forecasting over a broad regional scale, and does not have any station in the mountainous western portion of Montana.

This sparse data network is not even remotely adequate to measure conditions in the lower atmosphere with the detail needed to identify and understand local meteorological effects on air pollution. The MAPS staff, therefore, has found it necessary to establish a fairly extensive monitoring effort to meet the project needs. The MAPS Advisory Committee for Meteorology and Modeling made recommendations for the establishment of the meteorological network required to measure and describe the variability of those meteorological

parameters that influence atmospheric motion and turbulence in the prescribed study areas. Completion of the entire network was accomplished by August 1978. Each study area now has adequate monitors for several meteorological parameters, including surface wind speed and direction; upper level wind speed and direction; temperature and dewpoint; solar radiation and atmospheric turbidity; barometric pressure; temperature lapse rate and stability; and inversion formation, height and breakup. By coordinating the planning with other special studies of the Air Quality Bureau, and by utilizing existing data whenever possible, quite a thorough overall network has been provided at relatively minimal cost. A listing of the specific meteorological parameters measured is presented in Table 4; the following discussion is intended to describe the nature of the major parameters and the ways in which the data will be utilized.

SURFACE MEASUREMENTS

Wind Speed and Direction. A continuous record of wind speed and direction at sites selected which represent variations caused by the topography of the study area, is essential to understand and describe the drift and dispersion of pollutants released at or near the ground surface. Primary sites have been established at the major sites where the pollutants are being monitored; secondary sites have been established in each study area to measure the wind at representative points where the terrain influence causes a marked variation. The anemometers and direction indicators are installed on 10-meter towers at most of the wind recording sites.

TABLE 4

SUMMARY OF METEOROLOGICAL MONITORING NETWORK

Parameter	Anaconda	Billings	Butte	Missoula
Wind speed and direction	Lincoln School Highway 48 Junction Anaconda Co. (6)	Central Park NWS-Airport Horsehoe Hills	Hebgen Park FAA-Airport "Alpine West" MHD facility	Lions Park Steigler Site Olafson Site University Park Hoerner-Waldorf NWS-Airport
Solar radiation	Lincoln School	Central Park	Hebgen Park MHD facility	Lions Park
Turbidity	Lincoln School	Yellowstone County APC Office	Hebgen Park	Nursing Sch.
Temperature	Lincoln School Anaconda Co. (2)	Central Park NWS-Airport	Hebgen Park FAA-Airport MHD facility	Lions Park NWS-Airport
Relative humidity or dewpoint	Lincoln School Anaconda Co.	Central Park NWS-Airport	Hebgen Park FAA-Airport MHD facility	Lions Park NWS-Airport
Barometric pressure	Lincoln School Anaconda Co.	Central Park NWS-Airport	Hebgen Park FAA-Airport MHD facility	Lions Park NWS-Airport
Stability and inversion height	Highway 48 Junction	Vo-Tech site	MHD facility Airport site	USFS Fire Lab
Upper level wind	Highway 48 Junction	Vo-Tech site	Airport site	USFS Fire Lab
Precipitation	Anaconda Co.	NWS-Airport	FAA-Airport	NWS-Airport
Cloud cover and height		NWS-Airport	FAA-Airport	NWS-Airport
Visibility		NWS-Airport	Hebgen Park FAA-Airport	Lions Park NWS-Airport

Smaller Study Areas

East Helena: ASARCO Co. - complete set of above
Colstrip-Hardin: Complete set of above
Columbia Falls: Complete set of above

Solar Radiation. The influence of the sun's radiation upon the turbulence of the atmosphere and upon certain photochemical reactions makes measurements of radiation important in air pollution studies. In addition, the amount of incoming solar radiation may be reduced due to particulate matter in the air. Therefore, it is often desirable to measure this effect by comparison between urban and non-urban stations similarly instrumented. Continuous solar radiation measurements are included in the MAPS program at all primary meteorological station sites.

Atmospheric Turbidity. Fine particulates, dust, and various aerosols produce haze and reduce visibility. The presence of particulates characterizes a property of the atmosphere termed "turbidity." Turbidity means the degree of transparency of a cloud-free atmosphere to visible radiation. Turbidity measurements are made utilizing a relatively simple hand-held instrument called a sun photometer. Readings are only taken under clear skies when the sun is shining, and these readings reflect the degree to which incoming radiation is reduced due to air pollution. Turbidity measurements are included in the MAPS program at the primary meteorological station sites.

Miscellaneous. Several of the more traditional meteorological observations are also being taken in the MAPS program. Continuous records of air temperature, dewpoint (air moisture), and barometric pressure are being gathered at many primary sites, and all available data from National Weather Service Stations in the study areas are also being obtained and included in the data base.

UPPER AIR MEASUREMENTS

In addition to the more traditional surface measurements which are taken within fifty feet of the ground, an air pollution study also requires

measurements of winds and temperature throughout the atmosphere up to a height of several thousand feet. This is because the vertical temperature differences between the surface and the upper layers of air have a great deal to do with whether pollutants are widely dispersed or are trapped within the valleys where they can accumulate to high concentrations.

When the temperature change from the surface up to several thousand feet is a marked cooling, the air is mixed by strong vertical motion. Under these conditions, low-level pollutants, instead of being trapped over the area near the ground can rise and be carried away by the winds aloft, which are generally stronger than the surface winds. On the other hand, when the temperature change with increasing height shows only slight cooling, or when the temperature actually increases with height (a temperature inversion), very limited vertical air mixing occurs. When this occurs, the pollutants emitted at low levels are confined to the air nearest the ground and generally accumulate to higher-than-normal levels. If the source of low-level pollutants is a city within a valley, then the inversion or "ceiling" may combine with the valley walls to make an unventilated box, and pollutants may accumulate for several days. This meteorological circumstance underlies most of the worst air pollution situations that occur in Montana.

The MAPS meteorological program, as integrated with other special meteorological studies of the Air Quality Bureau, has two components, an acoustic radar approach and a pilot balloon program, that are involved with measuring the upper air parameters required to study and document these phenomena.

Acoustic Radar. An acoustic radar unit is an instrument that uses ultrasonic sound pulses and their echoes to detect temperature changes in the air, much like normal radar uses radio echoes to detect airplanes. It is a

relatively new, sophisticated piece of equipment which will provide a continuous, unattended record of the vertical temperature fluctuations and resulting air turbulence in the lowest 1000 meters of the atmosphere. When interpreted by a trained meteorologist, acoustic radar records are of considerable aid in determining how stable (stagnant) or unstable (rapidly changing and moving air currents) the atmosphere is at any given time. The MAPS project has provided an acoustic radar installation in the Billings area. Use of acoustic radars owned by cooperating agencies and those operated under other AQB studies also makes data available in the Anaconda, Butte, Kalispell and Missoula areas.

Balloon Soundings. Lighter-than-air balloons that have a known ascent rate provide an excellent means to measure meteorological conditions in the atmosphere. The National Weather Service operates a network of balloon soundings that provides a major input to their weather forecasting system. However, this network is much too sparse for use in predicting local variations in air circulation. As an example, in Montana the network has only two balloon sounding stations (Great Falls and Glasgow) and none in the western mountainous portion of the state. The closest adjacent soundings are at Spokane, Washington; Boise, Idaho; Lander, Wyoming; and Rapid City, South Dakota.

The MAPS program has established balloon sounding stations at Butte, Billings and Missoula, and sounding data is being obtained from other studies in Anaconda and Kalispell. Soundings that provide wind speed and direction as well as the temperature profile for the lower few thousand meters of the atmosphere are taken shortly after sunrise (when atmospheric motion is normally at a minimum) and in the afternoon (when atmospheric motion is

normally at a maximum). Helium-filled balloons are tracked with theodolites and positions are recorded at thirty-second intervals. A small and inexpensive temperature thermistor and battery operated radio sent aloft transmit a continuous record of temperature to a ground based recorder as the balloon rises.

SECTION V

HEALTH EFFECTS

In judging the degree to which air pollution (or any other influence) can affect human health and well-being, there is a variety of evidence which is relevant and needs to be considered in the process of making assessments and policy judgments. A large amount of medical and scientific literature exists concerning a wide variety of health effects that have occurred elsewhere. These include both acute effects, which occur in response to the day-to-day changes in air pollution levels in any given location, and chronic effects, which occur over longer periods of from several years to a lifetime; these latter become apparent through study of differing environments occurring in differing locations and their resulting effects. The types of effects that have been seen and studied elsewhere include not only the more obvious or more serious effects on death and serious illness, but also less apparent impacts on such things as the prevalence of minor lung problems and modifications in the basic physiological functioning of the respiratory system. All these effects have occurred elsewhere under certain environmental conditions and are things which might logically be assumed to happen in Montana under similar conditions.

A number of effects have already been observed to some extent in Montana. As mentioned earlier, there are high death rates in several counties of the State for groups of diseases that are generally believed to be attributable to pollutant exposures. Research studies by University of Montana students in Missoula have suggested a possible association between

particulate levels and respiratory-related hospital admissions. Toxic fluoride effects have occurred in animals, elevated blood lead levels have been observed in children, and many physicians have related anecdotal incidents of increased respiratory symptoms apparently due to air pollution exposures. Like the general body of medical and scientific literature, this miscellaneous collection of informal knowledge is enough to cause concern from medical and public health officials, as well as from individual citizens, but it is not the type of specific, quantitative information that is required to support major public policy judgments. Consequently, the MAPS research program is intended to provide better, more quantitative information, developed specifically with respect to the air pollution levels, meteorology, and population patterns of Montana.

In an effort to develop an air pollution and health research program which would be most effective and efficient, the Department's Air Quality Bureau formed a Health Effects advisory committee comprised of Montana physicians and others interested in and knowledgeable about the health effects of air pollution. This committee met with national experts in air pollution and health, including Dr. Carl Hays, of the federal Environmental Protection Agency's health effects research group, Dr. Benjamin Ferris, of the Harvard School of Public Health, and Dr. Douglas Hammer, an independent air pollution research consultant. The committee also met with Dr. Edward Perrin, a biostatistician from Battelle Northwest in Seattle, and had phone consultations with several other air pollution and health researchers. This was coupled over a period of several weeks with a review of literature on recent air pollution and health research and through numerous meetings and long distance phone and small committee conferences.

From these efforts, the Committee developed an approach to the health effects studies for the MAPS project that was felt to be effective, efficient, and well-balanced, using the most proven study techniques available. The studies are designed to provide well-organized, scientific conclusions which can be not only useful in relation to Montana public policy decisions, but are also reasonably defendable when and if those decisions should be questioned. The three major components to the overall program are: statistical studies of existing data, a major pulmonary function testing program, and a smaller mutagen screening program. The first component includes statistical studies of existing data on respiratory mortality, hospitalizations, and visits to physicians. These types of studies are not very sensitive, because they are apt to identify only the most severe pollution impacts on health; however, because they utilize data originally gathered for other purposes, they are quite cheap compared to studies generating new data.

The largest component, the pulmonary function testing program, includes two major types of studies - one in Missoula of patients known to have chronic obstruction pulmonary disease (COPD), and another of elementary school children in all the MAPS study cities. The study of COPD patients involves the on-going monitoring of the participants' breathing ability, and is intended to permit study of acute air pollution impacts on a short-term, week-to-week, basis. The study of school children, in contrast, is primarily designed to study possible long-term, or chronic, effects by comparing similar populations living in different atmospheric environments, that is, in the different study cities. The pulmonary function measurements made in both these studies are primarily sensitive to the type of

pollutants that are respiratory irritants, such as particulate matter, sulfur oxides, and nitrogen oxides.

The mutagen screening program is directed toward roughly assessing the environmental risks of cancer, although the many unknowns involved in cancer causation mean that the screening must be very general indeed. This study, concentrated initially in Anaconda and Butte, involves testing children's urine samples and air pollutant samples with standard microbiological mutagenicity tests.

The remainder of this Section describes in much more detail the implementation of each of these study components.

STUDIES OF EXISTING DATA

The specific studies undertaken in this category include a major review and improvement of the information on mortality in the State's vital statistics data base, and smaller studies of morbidity (illness) through the use of existing data on hospitalizations statewide and physician visits at one major clinic in Missoula. The mortality study, also informally referred to as the "death certificate study," is an initial investigation into some possible causes of the high number of deaths from lung cancer and respiratory diseases in Deer Lodge, Lake, and Silver Bow Counties. Surviving relatives of persons who died of lung cancer, chronic respiratory diseases or strokes will be interviewed to provide additional information on smoking, occupational, and residence history that is not available on the routine death certificates. In the morbidity studies, existing data on physician visits and hospitalizations are being tabulated for purposes of comparison with short-term pollution level patterns.

Death Certificate Study

A review of Montana's vital statistics for the period 1968-1973 revealed noticeably high mortality rates from chronic obstructive lung disease (emphysema, asthma, chronic bronchitis), cerebrovascular disease, and cancer of the respiratory system in certain counties of Montana. These rates, particularly in the 40 to 65 age group, were significantly higher when compared with the rest of the counties in the state as well as with the United States as a whole.

The Department applied to the EPA Health Effects Research Laboratory for funding and technical assistance to study these rates in detail, and EPA did partially fund, and assist in designing, a state-wide death certificate review (Phase I) and a detailed mortality study in Deer Lodge, Lake and Silver Bow Counties (Phase II).

For Phase I of the study, the Department's Bureau of Records and Statistics provided to EPA selected data from the death certificates for all persons who died in Montana from 1970 through 1975 from the following diseases:

	Disease Code*
1. Cancer of the respiratory system	160-163
2. Chronic obstructive pulmonary disease	491-493
3. Cerebrovascular disease	430-438

EPA statistical personnel selected a balanced study group of 300 certificates in Deer Lodge, Lake, and Silver Bow Counties, and a matched control group of certificates for persons who died in the same counties from diseases other than the three categories above.

*According to the "International Classification of Diseases Adapted"

In March 1978 the Bureau contracted with the Montana Foundation for Medical Care (MTFMC) to conduct the Phase II field work for this study. In this effort, MTFMC personnel are first locating the clinical records of individuals in both the study and control groups to obtain any available information on the smoking habits, alcohol consumption, and other diseases or conditions of the deceased, as well as the family's history of diseases.

After these data are collected and reviewed, MTFMC personnel will locate and interview the closest surviving relatives of the deceased in both the study and control groups to request further information on the background of the deceased. The questions posed to the surviving relatives will concern smoking habits, alcohol consumption, disease history, length and location of residence, deceased's occupational history for the previous thirty years, and the type of heating and cooking fuels used in the deceased's home. MTFMC personnel will also locate and mark residences of the deceased on a map in order to determine if any relationship exists between mortality rates and specific areas of the counties.

Morbidity Data Studies

Morbidity studies are designed to investigate possible relationships between air pollution and illness in an exposed population. Obviously, respiratory symptoms and illnesses have the highest probability of being related to air pollution; however, evidence exists that heart disease, depression, and other psychological illnesses may also be related to air pollution. Therefore, MAPS is seeking to determine if there is a relationship between these illnesses and air pollution in Montana.

It is relatively expensive to use a survey of households or some other primary data-gathering mechanism to obtain data on illness that is

chronic. Therefore, many epidemiological studies of morbidity rely on data collected for other reasons by either physicians' offices or hospitals, and MAPS is pursuing these data sources in Montana.

There are some limitations to, and difficulties with, such studies. A person may have symptoms of a respiratory disease for two or three days prior to visiting a physician as an outpatient; thus, a lag period after an insult such as air pollution may exist and must be considered. Further, only a small fraction of the persons who may experience respiratory symptoms will actually visit a physician, and even a smaller fraction will be actually admitted to a hospital. Therefore, any hospital data tend to be relatively insensitive, because of lag period and also because only the most severely affected are hospitalized. In spite of these problems, however, epidemiological data from large populations suffering from severe air pollution episodes have shown a correlation with hospital admission; consequently, an analysis of data from Montana is being conducted to determine if such an association exists here.

In Montana, the MTFMC has data for approximately 60 percent of all hospital admissions. Those are the admissions financed by federal funds (Medicaid, Medicare, U.S. Public Health Service, and CHAMPUS). MTFMC is providing its data for MAPS analysis, which will seek to determine if an association exists between the illness categories above and air pollution exposure.

A similar study of all outpatient visits to physicians at the Western Montana Clinic in Missoula will analyze the same parameters. Data for this effort are being made available by the clinic from its financial billing system, and are being summarized for analysis by MAPS personnel under the clinic's supervision.

PULMONARY FUNCTION TESTING

The lung is the organ most likely to be affected by air pollution. The normal adult at rest inhales and exhales approximately six liters of air per minute. Therefore, during a twenty-four hour period or during a lifetime, the lung may be subjected to enormous insults by any foreign material present in the air. Over a long period of time, and sometimes over only short periods, this insult can affect the basic physiological functioning of the lungs, impairing or changing the organs' ability to perform their function. Consequently, monitoring of the lung's capabilities, or pulmonary function testing, has become a standard approach for objectively assessing respiratory insult; it is used in most other major research projects, and was adopted as one major component of the MAPS health effects studies.

There are three different physiological functions of the lung that can be tested to determine the extent of impairment due to disease or injury. These are the total air capacity of the lung, the ease of air flow in and out of the lung, and the ease of gas exchange between the air in the lung and the blood in the circulatory system. Only the first two of these, the lung capacity or size and the rate of air flow, can be measured simply enough to be considered for mass pulmonary function testing. Measuring the gas exchange rate requires both time-consuming and expensive testing, and direct medical supervision.

In both of the major pulmonary function testing studies, five specific parameters of lung performance, involving lung capacity, air flow rate, or both, are measured by means of a pulmonary spirometer. A spirometer is a piece of equipment containing a bellows, a balanced piston, or some other

means of measuring the amount of air breathed out during a strong expiration, and the speed with which it is expired. The test subject takes a deep breath, and then breathes out as hard and fast as possible through a flexible hose into the machine. The Jones Pulmonor, the spirometer used by MAPS, has a lightweight bellows which moves in response to the incoming airflow and creates a graph of the amount of air moved vs. time, as in Figure 6. From this chart record, the following different parameters are calculated by an attached small computer and used as measures of the lungs' performance.

Forced Vital Capacity (FVC) This is the total amount of air that can be breathed out; it is measured as the highest point on the chart, when the curve flattens out at the end.

Force Expiratory Volume ($FEV_{1.0}$ and $FEV_{0.75}$) This is the volume of air that is expired during a certain initial period of time; MAPS records two such parameters: the FEV in one second, that is the amount of air that can be expelled in the first second, and the $FEV_{0.75}$, the amount in the first three-fourths of a second.

Forced Expiratory Flow Rate ($FEF_{.25-.75}$) This parameter measures the speed or rate at which the air can be expelled, which in turn reflects the airflow resistance of the medium-sized and smaller-sized air passages of the lungs. This airways resistance is highly dependent upon possibly inflammatory or structural changes due to infection, allergy, or other insults such as air pollution. The parameter is calculated as the average flow rate for the middle half of the air moved, that is, between the 25 percent point and the 75 percent point.

Peak Expiratory Flow Rate (PEFR) This is the single highest flow rate, that is, the steepest slope of the curve on the chart. Usually this occurs at the beginning of the expiration, reflecting the effort needed to overcome the inertia of the static volume of air and get it started moving out the large airways.

The various lung function parameters recorded differ in part because they reflect different aspects of lung function. However, they

also differ in their precision or reliability as well; some are more effort-dependent than others. The term "effort-dependent" means that the numerical value for a parameter in any given test is dependent on the degree of effort the test subject puts into the force exhalation. All the test results are of course sensitive to having the subject exert a "good" effort, but some are much more so than others. The forced vital capacity (FVC), for instance, is the least effort-dependent, so that numerical values of FVC from good tests are quite accurately repeatable. In contrast, the PEFR values are extremely effort-dependent; imperceptible differences in the subjects' efforts can cause significant numerical differences in the data. The more effort-dependent parameters thus have a greater internal statistical variability, and any change produced by an external cause will be more difficult to detect.

The complete procedure testing for pulmonary function is described subsequently in the discussion of the school children study and in some appendix material. The pattern of testing and the detailed procedures used have been designed carefully to maintain consistency with other studies conducted elsewhere.

COPD Patient Study

The first study group is composed of adult patients known to have chronic obstructive pulmonary disease (COPD), which includes emphysema, chronic bronchitis, and asthma. If air pollution at the levels experienced in Montana cities causes respiratory insult, it is expected that these members of the population would be among the most sensitive, and would be expected to exhibit noticeable deterioration in lung function during periods of higher air pollution exposure. Because of this sensi-

tivity, the COPD patient study offers by far the best possibility of directly relating short-term changes in measured levels of air pollutants and measured values of pulmonary function, and for identifying the particular air pollutant responsible for the effect. However, the COPD patient study, like all such panel studies, must rely heavily on excellent cooperation from a sizable number of volunteers over a long period of time, a degree of volunteer effort that is commonly felt by researchers to be difficult to obtain. Consequently, the COPD patient study is being pilot tested in Missoula, where a known high level of environmental concern is expected to provide the best chance for success. If it proves possible to maintain an adequate degree of participation in Missoula, similar studies may subsequently be conducted elsewhere.

The design of the COPD study was based on the participation of eighty to one hundred persons, with each subject being tested once every four weeks. Thus, twenty to twenty-five persons are tested each week, so that a continuous coverage of time is obtained without demanding excessive effort from each individual. Anticipating that subjects would be lost to the study over time, more than one hundred persons were originally sought, and continuing efforts to obtain additional participants are maintained. The characteristics sought in subjects enlisted for the study are the following:

1. Diagnosed chronic obstructive pulmonary disease, preferably confirmed by an abnormal pulmonary function test.
2. Currently not smoking and willing to not smoke for the duration of the study.
3. Currently ambulatory and performing normal employment or homemaking tasks.
4. Not subject to unusual occupational air pollution exposure.

5. Living in the urban Missoula airshed.

Several methods of recruiting participants were utilized, with varying degrees of success. The initial effort was a request by letter that local physicians refer names of their respiratory patients to the study. The response to this was minimal, even with followup phone calls, apparently because of the inconvenience associated with identifying patients from individual physicians' records.

As a second approach, the computerized billing records of the Western Montana Clinic, a large group practice, were utilized to provide a list of respiratory patients. With the approval of the individual physicians, phone calls were made to the patients identified by MAPS personnel, asking their participation. This process was by far the most productive, yielding about seventy persons who initially agreed to participate. One individual respiratory specialist in Missoula made his patient list available, with the study personnel contributing the effort to identify and contact patients; another twenty-three recruits were developed from this group.

There has been a continuing series of public service announcements and appeals on radio and television, and these have yielded eighteen participants to date. The Retired Senior Volunteer Program, a local senior citizens service group, also recruited several volunteers. Altogether, about one hundred twenty (120) initial volunteers yielded some one hundred subjects who fit the criteria and began the study.

Testing of the COPD patients began on January 7, 1978. The subjects come to the MAPS office once per month for pulmonary function tests. The pulmonor produces a graph which indicates volume in liters and flow rate in liters per second, as in Figure 6 , and a small computer attached to

the pulmonor prints the numerical measures of volume and flow rate on a paper strip. The subject is given three tests at each session, and the two best efforts are recorded for the study.

In order to account for other variables, each participant was asked to complete a background questionnaire before the first test to obtain information about occupational history, present dust or fume exposure, current health, past respiratory and cardiac health, and smoking and allergy history. At the time of testing, a record is made of the subject's height, weight, and elapsed time since any medication, as well as the temperature inside the testing room and outdoors. In addition, for seven days prior to the test, the subject keeps a daily log of changes in health, changes in activities, use of medical help, or unusual air pollution exposure. This provides a daily sympton record, including weekends and holidays, that can be compared to short-term air pollution exposure changes.

As anticipated, there was some initial subject attrition. Of the 100-plus original participants, about twenty have left the study; eight of these simply lost interest, and the balance were divided among people who became too ill, found that they could not stop smoking, or moved out of the Missoula area. With a few on-going additions, the study now has a fairly stable population of about eighty participants.

A variety of efforts has been undertaken in the Missoula study to show appreciation for the volunteers' participation in the COPD study. For example, a coffee hour was held in June 1978 for all the subjects, and the staff explained to them the total study and their importance to it. A special parking space was reserved for the project to facilitate

access to the building, an important consideration for victims of emphysema. However, it is ultimately the responsibility of the pulmonary function testing team to maintain enthusiasm for the program and to make each visit as pleasant as possible.

School Children Study

The other major pulmonary function testing study being conducted under MAPS involves the use of a group of elementary school children in the third and fourth grades. The U.S. Public Health Service, the Environmental Protection Agency, and various academic researchers have used and are presently using this type of study to evaluate air pollution health effects in other areas of the country or world. Thus, comparisons are possible among school populations in Montana and elsewhere. Elementary school children are used for these studies primarily because they are not affected by smoking and occupational exposures; it is also economical because they provide a large stable population that is available for testing as groups in a few locations. In order to evaluate any possible effects of short-term air pollution exposures on the children, it is necessary to try to relate changes in the children's pulmonary function over time with measured variations in air pollution. It is not well-known whether healthy children's pulmonary function changes enough in response to short-term changes in pollution exposure to be detectable. However, it has been clearly seen elsewhere that, over a period of several years, children who grow up in a higher-exposure environment show a clear degradation of their pulmonary function. Consequently, the overall school children study is designed to look both for short-term, month-to-month changes in the children of any specific school, and also long-term develop-

mental differences among children in the various study communities.

Two pulmonary function technicians were hired and trained in November 1977, to be based in Missoula. In addition to the COPD patient study described above, these people began a pilot program in Missoula schools, based on testing each child monthly. Preparation for the pulmonary function testing program in a given city or school district begins after approval is obtained from the local school board and the principals of the schools involved. A testing schedule for the schools is determined, in consultation with each school principal, taking into consideration the following requirements:

1. Tests at each school should be made in the morning, for consistency, since pulmonary function may change measurably from morning to evening.

2. Testing days at the various schools should be spread out during each week and month for a good coverage of different ambient air conditions.

3. Physical education classes and recess periods should be avoided.

4. Schools with more than fifty students must be divided into two testing days.

5. The MAPS team is the guest of the school and must accommodate special needs, attempting to minimize any disruption of class time.

After the testing population is selected, permission letters are distributed to the school principals so that each child takes one home for a parent's signature. Parents who do not return the permission letters are given follow-up telephone calls in an effort to include all students. The parents also are asked to complete a questionnaire containing background information, such as birthdate, race, duration of residence, home smoking exposure, past respiratory health, and socio-economic status.

Each student is assigned an identification number for use throughout the two-year study. New students also are enrolled in the study as soon as possible.

The testing team begins by bringing the equipment into the classroom to demonstrate how the testing is done. Having seen a demonstration, the children need less time for explanation at the actual time of testing, and gain enthusiasm for the program. The testing is done in a separate, quiet room where the children will not be distracted. A volunteer from the PTA, the local health department, or the medical auxiliary brings the children from the classroom, approximately four at a time. The volunteer takes height and weight measurements, records them and the child's age and sex on the graph papers to be placed into the machines, inquires about any recent illnesses, and generally keeps order among the children. Each child is then tested by one of the technicians, obtaining at least three good tests so that the best two efforts can be recorded for the study.

After the testing in a particular school is completed, the technicians contact the school or the parents of any absent student to determine whether the cause of absence is related to a respiratory problem. Each child's test is examined, using both the printout and the curve on the graph to select the best effort, and the technician marks the two best tests for use in the statistical analysis.

The Jones Pulmonor-Datamatic combination is a sophisticated and delicate piece of equipment which, while portable, is not really designed for as much transporting as the school children study has required. Equipment difficulties were common during the beginning of the study; however, adjustments have improved the dependability of the equipment, and addi-

tional experience and a contract with the medical engineer at St. Patrick's Hospital in Missoula for maintenance and repair work have virtually ended the problems.

A quality assurance program for the pulmonary function testing has been established to provide a guide to overall data accuracy and precision. The approach used in this study is to continuously monitor the instruments' critical parameters over time, and to make adjustments at any time the parameters exceed a predetermined limit. The quality assurance program will be described in detail in a subsequent report.

The school children pulmonary function study was pilot tested in Missoula during the 1977-78 school year. A study population of eleven schools in the Missoula urban airshed was chosen (Lowell, Roosevelt, Franklin, Lewis and Clark, Russell, Willard, Whittier, Jefferson, Washington, Dickinson, and Paxson Schools). A total of 585 students began in the study, representing 91 percent of those eligible. Movement of the children's families reduced this to 561 participating during the last month of the study. Because the testing was done in just one city, the primary interpretation of the results will need to be directed toward longitudinal comparisons of different geographical locations. The sample-every-month nature of the pilot study in Missoula was in fact designed to assess just how important the longitudinal changes with time would be in school children, and so help in selecting the intensiveness of the measurement program in the other study cities.

Although primarily longitudinal in the eleven Missoula schools, the first year's study program did include some preliminary testing for purposes of geographical comparison. One hundred students were tested in

the suburban Target Range School west of Missoula at the end of January 1978. On February 3, 1978, seventy third and fourth grade students were tested in Clinton, a town east of Missoula and in a different valley. Subjectively, these two areas appear to have a lower level of air pollution than does central Missoula.

In May 1978, a major two-week testing program was undertaken in the Great Falls schools, with the purpose of viewing Great Falls as a non-mountainous, somewhat less-polluted, comparison city. In any study such as this, where the variables of concern (environmental exposures) are beyond direct control, it is necessary to seek differences that occur naturally. The existing data gathered by the Air Quality Bureau, as well as general knowledge about air pollution sources, topography, and meteorology, indicate that Great Falls likely would show the greatest difference in air pollution levels compared to the other large cities. During the original planning of the MAPS project, inclusion of Great Falls as a major study city was considered; however, financial limitations on the project scope precluded committment to a full-scale effort at that time, and the one-time visit to Great Falls was adopted, along with the knowledge that Billings might also prove to be sufficiently different from the other cities to serve as a good comparison.

Based on initial analyses of the first year's data, some re-formulations of the school children study have been made in expanding it to the other cities for the 1978-79 chool year. With only limited analysis, the month-to-month pattern of change in the Missoula children's pulmonary function was not indicative of significant response to short-term changes in air pollution levels or any other factor. However, neither was it so

uniform and unchanging as to imply that there were no short-term changes.

Consequently, a combination approach was taken toward the 1978-79 program. In Missoula, the month-to-month testing of the same children will be continued; that is, the third and fourth grade students will be followed into the fourth and fifth grades. The cross-sectional study comparing different cities, however, will be designed on a sampling schedule of three testing periods per year, rather than the eight that the monthly testing involves. Great Falls has been included as a nonmountainous comparison, not only because the less intensive sampling schedule makes it economically possible, but also because the Billings public schools declined to cooperate with the study.

MUTAGEN SCREENING ANALYSIS

The third major component of the health effects monitoring effort, proposed and conducted by the MSU Chemistry Department, is a screening program concerning mutagens, substances that are capable of causing mutations, or abrupt changes in the genetic material of the cells. Measurement of the mutagenic potential of substances by means of microbiological procedures known as Ames tests has recently become a fairly standard approach throughout the country to assess the carcinogenicity of substances, that is, their potential for causing cancer.

The Ames test, which was developed by Dr. Bruce Ames and his colleagues at the University of California at Berkeley, is based upon the premise that carcinogenesis and mutagenesis both apparently involve damage to the genetic material of cells. This premise suggests that mutagens are likely to be carcinogens and vice versa. The Ames test predicts whether a substance will be carcinogenic on the basis of its mutagenicity

in certain strains of the bacteria E. coli and Salmonella typhimurium. The bacteria strains have been modified so that they need an external supply of a certain nutrient (the amino acid histidine) in order to survive. If they are exposed to a mutagenic substance, mutations will occur in some of the bacteria, causing them to revert to the unmodified, or wild, type; these "revertants" regain the ability to make their own histidine, and thus to survive and grow without an external source of the nutrient.

In testing a substance, the bacteria are placed in a dish with a nutrient medium that does not provide enough histidine for them to survive. The test compound is added to some dishes; the others are kept as controls for comparison. If the test substance is mutagenic, colonies of bacteria will appear and survive because some of the bacteria have reverted to the wild type and are producing the histidine they need to live. If significantly more colonies survive in the test dishes than in the controls, the compound is judged to be mutagenic in bacteria and probably carcinogenic in animals and humans. This latter link, suggesting that whatever is mutagenic to the bacteria is also carcinogenic in higher animals is of course not proved by the microbiological Ames test; it is proved by much more extensive carcinogenicity tests on laboratory animals. However, the relationship shown by these tests is very strong - well over 90 percent of chemical substances that show up positively on the Ames bacteria mutagenicity test have also been shown to be carcinogenic in animals. Thus the Ames test, while obviously complex, is considered to be a very reliable screening tool for checking the carcinogenicity of various chemicals. It is extensively used, for instance, to study the safety of pesticides, food additives, drugs, and other potentially harmful new chemicals.

The Ames test is used in the MAPS study as the best available approach to get some indications on the extent to which carcinogenic chemicals are part of environmental exposures, since lung cancer is one of the respiratory diseases for which increased death rates have been seen in Montana. MAPS is using Ames testing in two distinct ways - in studying population urine samples and in testing collected atmospheric pollutant materials.

The latter of these, the testing of atmospheric pollutants, is similar to testing drugs or other chemicals, except that the substances to be tested must be first filtered from the air and then extracted from the filter medium in the laboratory. This latter step, getting the potentially carcinogenic materials off the filter paper without destroying them, has proved to be a very difficult one. It is still very much a research-level problem, with the Chemistry Department Laboratories at MSU being one of only a few locations in the country where such work is being successfully carried out. An extensive series of analyses of air samples has not yet been undertaken, but the results from the samples analyzed in the process of refining lab techniques have all shown the presence of carcinogenic materials in the air.

The second way in which MAPS is utilizing Ames tests is in screening human populations via urine specimens. That is, the chemicals being tested for implied carcinogenicity are substances excreted in the urine, presumably being derived from other substances taken in by the body from the air, water, or food. This unusual approach was proposed by the University researchers because of other studies that showed heavy smokers, known to have a very high lung cancer rate, also had high levels of carcinogenic metabolites in their urine.

The urine testing is currently being conducted on elementary school children at the elementary schools nearest the MAPS monitoring sites in Anaconda and Butte, where lung cancer rates are high, and in Bozeman as a comparison.

During May 1978 samples were collected for urinalysis from forty-seven third and fourth grade volunteers at Monroe School in Butte and from forty-three third and fourth grade volunteers at Lincoln School in Anaconda. These grades were selected, as in the pulmonary function testing, because the age of the children is low enough to restrict the number likely to be smokers. Parents of the students were requested to complete questionnaires to determine the types of home heating system employed, smoking habits, occupation, obvious sources of air pollution exposure, and an impression as to the incidence of cancer in the person's neighborhood during the previous five years. Air samples from days the urine samples were collected and from the preceding days are also being analyzed for mutagenicity.

Urine samples from the same elementary school children were taken again in October 1978, and samples will be collected from a similar population in Bozeman for comparison. Because the preliminary results from the May samples showed an unusual geographical clustering in Butte, an additional school there (Emerson) was also included in the October tests.

SECTION VI

EMISSION INVENTORY

An emission inventory, an unusual air pollution concept, is easily described in terms of the two components of the title. From an air quality standpoint, an emission is any liquid, solid, or gaseous material, which is released into the atmosphere and is capable of causing physical or economic damage to humans and their environment. Since an inventory is an itemized list describing the quantity of materials available, the term emission inventory describes a list of the amount and type of air pollutants being released into a particular area during a specific period of time.

Most traditional emission inventories are based upon annual averages, i.e., annual totals of amounts of pollutants emitted. Such inventories are usually accomplished through different mechanisms corresponding to the two major classifications of emission sources; i.e., point and area. A point source is a stationary source emitting more than a specified amount of pollutant. Examples of point sources include refineries, smelters, sawmills and paper mills. Area sources, on the other hand, are small dispersed pollution sources which do not lend themselves well to individual analysis. This category includes emissions from automobile exhaust, residential heating, and fugitive dust.

Emission inventories are a source of information with many uses. Probably the most important functions of such inventories are environmental planning, control strategy development, and enforcement. An accurate emission inventory, in combination with necessary meteorological data and an appropriate model, can be used to make predictions of present and future air pollution levels at various points within a given area. By identifying air pollution problem

areas and quantifying each source's contribution, an emission inventory can assist in the design of control strategies and resulting enforcement action.

The MAPS emission inventory was designed to include several unique features which are not usually included in such studies. The following discussion of each individual task in the MAPS emission inventory will describe some of these features.

Improvement and Expansion of the Emission Inventory

Prior to the commencement of MAPS, the emission inventory maintained within the Montana Air Quality Bureau was an annual system that was in many areas out of date. In addition, the inventory dealt only with five major pollutants: sulphur dioxide, total suspended particulate, carbon monoxide, hydrocarbons and oxides of nitrogen.

During the planning stages of MAPS, it was concluded that the existing inventory was inadequate for a health effects study. The planning staff decided that other pollutants, such as trace metals (lead, arsenic, cadmium, etc.), sulfates, and respirable particulates could present significant health hazards and should be included. In addition, the extreme meteorological conditions existing in Montana's mountain valleys, combined with seasonally changing emission rates, demanded a monthly inventory as opposed to the standard yearly analysis. The monthly aspect of this study becomes extremely important when relating to acute health effects.

The update and improvement of the emission inventory has been contracted to Midwest Research Institute (MRI) of Kansas City, Missouri, a major environmental research firm. At present, MRI has completed most of the study effort. The scheduled completion date is December 31, 1978.

MRI personnel have reviewed Montana's existing emission inventory to ascertain its strengths and weaknesses and discovered considerable shortcomings in both the point and area source inventories. MRI has spent considerable time in Montana cooperating with Air Quality Bureau and local agency personnel in the development of localized emission factors which apply to Montana. MRI has done extensive sampling of surface material within the study areas of Deer Lodge, Missoula, Silver Bow and Yellowstone Counties with regard to paved roads, unpaved roads, agricultural soil, tailings, slag, copper mining haul roads, and refinery coke. These samples have undergone analysis for particle size and have been used to calculate road surface dust loadings.

Preliminary results have shown that major arterial streets in Butte, Billings, and Missoula appear to have dust loadings similar to those found in other American cities. However, some residential streets have shown very high loadings, especially in Butte. The samples will undergo further analysis for trace metals and density. The information from these analyses will be used to calculate emission factors for the appropriate area source. Further sampling throughout the year will also be conducted.

MRI is also conducting an extensive literature search to determine the best available emission factors for Montana's sources. This effort will isolate emission data pertaining to the types of sources existing in Montana; it is especially important with regard to particle size and trace metals due to the lack of information in the state.

Butte-Anaconda Historical Emission Inventory

Because of the long incubation period (twenty to thirty years) for chronic respiratory diseases, the MAPS staff felt that an attempt to put

some historical perspective on the emission inventory for Butte and Anaconda would be very advantageous. In January 1978 the Bureau signed an agreement with Historical Research Associates (HRA) of Missoula to perform six-month feasibility study to determine whether reliable quantitative emission estimates could be made over a period from approximately 1880 to the present.

HRA has examined many diverse sources of information, including the Montana Historical Society, the University of Montana archives, the Montana School of Mineral Science and Technology library, personal interviews, city-county agencies, and local industries. They have gathered both qualitative and quantitative information on the following activities:

Industrial and commercial activity:

- nature of process and equipment used
- location within area and period of operation
- production levels or quantities of materials processed
- emission levels or estimated emission levels

Domestic acitivity:

- nature of fuels used for home space heating, cooking, and indoor lighting
- types of devices using above and quantities of fuels consumed
- methods of transportation used; i.e., number of motor vehicles, etc.
- miles of paved road and unpaved road
- historical population shifts within the Butte and Anaconda urban areas

HRA submitted its draft report to the Bureau in June 1978. The HRA report supplies the above information chronologically by source category, along with a narrative describing which data are available as well as their significance. In addition, a bibliography of all appropriate technical papers has been submitted to the Bureau. Bureau personnel and an engineering consultant have evaluated the report to determine the feasibility of establishing emissions estimates from the historical data, and it has been decided not to pursue the effort further at the present time.

Real-Time Emission Inventory

The real-time emission inventory is a daily inventory designed to coincide with the pulmonary function testing in progress under MAPS. Air Quality Bureau personnel are performing this task, with cooperation from the Missoula City-County Health Department. Since monthly pulmonary function testing is going on only in Missoula, this inventory has been limited to that area.

Currently, the woods-products industry and statewide slash burning are providing daily production data to either the Bureau or the local health department. The Missoula County Health Department is also logging daily information concerning other stationary sources in the area, road and street fugitive dust conditions, and open burning. Some area sources which do not lend themselves well to daily analysis are being handled by correlations with other measurable variables such as meteorological data.

The daily emission data collected under this task will be analyzed with meteorological and pulmonary function testing data in an attempt to correlate any relationships which may be ascertained between human health effects and air pollution exposure.

SECTION VII

STATISTICS AND DATA SYSTEMS

The extent to which the MAPS project ultimately succeeds depends in large part on how well the information it develops can be used to determine the seriousness of the air pollution situation in the cities studied.

Data acquired must be processed, analyzed, and perhaps more importantly, stored in a form readily available for further analysis. Therefore, MAPS has emphasized the development and expansion of data retrieval and storage systems. MAPS efforts along these lines fall into several categories, as follows:

Data Processing

The first step in data processing is to convert the information collected into a form that can be placed into a computer. MAPS data on air quality and meteorology are processed with the same personnel and procedures used for Air Quality Bureau data, although the volume of material generated by MAPS made it necessary to hire some additional personnel. The manpower requirement for such processing will be reduced substantially by automatic electronic data recording machines purchased by MAPS.

Data from the pulmonary function testing are processed by a small computer on each spirometer. The computer calculates the data from the raw signal, and prints the results on a paper strip. The strip data are checked by technicians and key-entered into a computer that checks the data for validity and creates the printed reports and computer tapes needed for further analysis.

Air Resources Data Bank

The goal of establishing a data bank to ensure the data is readily available has been approached through the modification of a computer system obtained from the federal Environmental Protection Agency. The federally-developed computer system was obtained from EPA at no cost and hence proved to be the cheapest way for the state to obtain such a system.

Under a contract with a Helena computing firm, systems analysts have been working with the Air Quality Bureau to tailor the system to meet State needs. This has included expanding the system to accommodate the data on particulate size from the dichotomous samplers and the extensive meteorological data gathered under MAPS. Current efforts are directed toward providing specialized retrieval capabilities that are needed for Bureau and MAPS activities. One such retrieval capability, for example, draws on both the air quality and pulmonary function data files to create combined computer tape files for the statistical analysis of health impacts caused by air pollution.

Air Resources Modeling System

The computer modeling of meteorological conditions and their effects on pollution concentrations is particularly important in Montana. For example, such modeling provides the main impetus in deciding whether new industrial sources would cause air pollution concentrations in violation of ambient air quality standards. Modeling also can predict how much the emissions of existing sources must be reduced to comply with standards.

Many models have been developed to make such predictions, but most of them are of limited usefulness in Montana, where the meteorological effects of complex and variable topography exceed the capacity of models developed for other areas.

The aim of the Air Resources Modeling System developed by MAPS is to provide analysis of local meteorological influences which can then be incorporated into a modeling system capable of providing more accurate predictions of ambient pollution concentrations likely to result from a given source.

Modeling personnel from the Air Quality Bureau, and experts from the advisory committee and the EPA, cooperated to select the models most applicable to Montana. Data from the MAPS meteorological monitoring sites are being used to adapt these models to localized Montana conditions. Incorporation of the models into the computer system is being undertaken by contracted computer programmers.

Statistical Analysis

Three major objectives of MAPS depend on statistical analysis. These three, as indicated in Figure 1, are determining whether there is correlation between health effects and air pollution, the identification of the sources causing the pollution, and the development of an understanding of how meteorology affects pollution concentrations.

All three of these objectives are being pursued under a cooperative effort among the staff of the Air Quality Bureau, statisticians from MAPS and the University of Montana and Montana State University. Three ad hoc steering committees were formed to oversee and guide efforts in the three areas, and to provide a communication link among the various personnel.

SECTION VIII

CONCLUSION

Determining the effect of air pollution on human health under any given set of circumstances is difficult. The MAPS program in its efforts to correlate air pollution and human health effects reviewed the methodology and results of such studies done elsewhere. Some elements of these studies were applicable to Montana, and were adopted by MAPS.

In other cases, the particular conditions in Montana, such as the types of pollution sources, the wide scattering of populations, the specific weather patterns and meteorological and geographical influences, required an approach tailored to the situation. Only in this way can the results reflect the actual pollution situation in Montana.

With the help of some of the foremost experts in the field, MAPS has systematically chosen and instituted a study approach especially designed for Montana. The results of this effort will be detailed in a series of reports which will follow in the next few months.